TUM – Courses
IN2045
Network Analysis – statistical and formal models and methods

Dr. Heiko Niedermayer, Cornelius Diekmann
(many slide sets from lecture Simulationstechnik by Prof. Alexander von Bodisco)

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Technische Universität München

Course organization

- Old course IN2045 "Simulationstechnik"
  will be changed into
  "Netzwerkanalyse – statistische und formale Modelle und Methoden"

- A lot of topics and slides from the old course will be reused.
  - Most of them are from Alexander von Bodisco.
  - Other contributors to his slides will be mentioned on the slide set where applicable.

- There will be
  - Less: simulation, construction of simulators
  - More: measurement, models and modelling aspects
  - New: formal methods such as Higher-Order Logic, multi-disciplinary considerations
  - Tools: Python / Scipy / Numpy, Isabelle/HOL, ….

Course organization

- Lecturer
  - Dr. Heiko Niedermayer, niedermayer@net.in.tum.de
  - Cornelius Diekmann, diekmann@net.in.tum.de
  - Prof. Dr. Georg Carle, carle@net.in.tum.de
- Course
  - Lecture and Exercise share same time slots. Exercises will be announced.
  - Tuesday 16:00-18:00, Room: 03.07.023
  - Thursday 14:00-16:00, Room: 03.07.023
- ECTS:
  - 5 credits
- Exam:
  - Written exam or oral exam at the end of the semester.
- Course Material:
  - http://www.net.in.tum.de/de/lehre/ss14/vorlesungen/netzwerkanalyse-statistische-und-formale-modelle-und-methoden

Course organization

- Exercises:
  - Will not be corrected.
  - We want voluntary participation and presentation of solutions.

- Teaching Concepts:
  - Lecture, Exercises + more interactive methods will be applied in both

- Goal:
  - Get familiar with statistical issues (statistical significance)
  - Get familiar with models and modelling
  - Learn how to model systems
  - Learn how to evaluate different systems (formal/simulation/measurements)
  - Learn how to analyze results by using related tools and methods
  - Learn how to visualize results

⇨ **Prepare students for their BA/MA thesis**

Course Outline

Tools and methods will be introduced applicable and suitable in the particular modelling context.

Outline:

- Short Introduction to Modelling
- Discrete Deterministic Modelling
- Modelling of Systems with Randomness
- Advanced topics: e.g. Internet Science

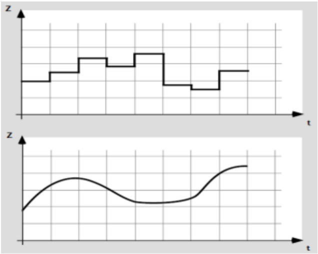
From the Old Course

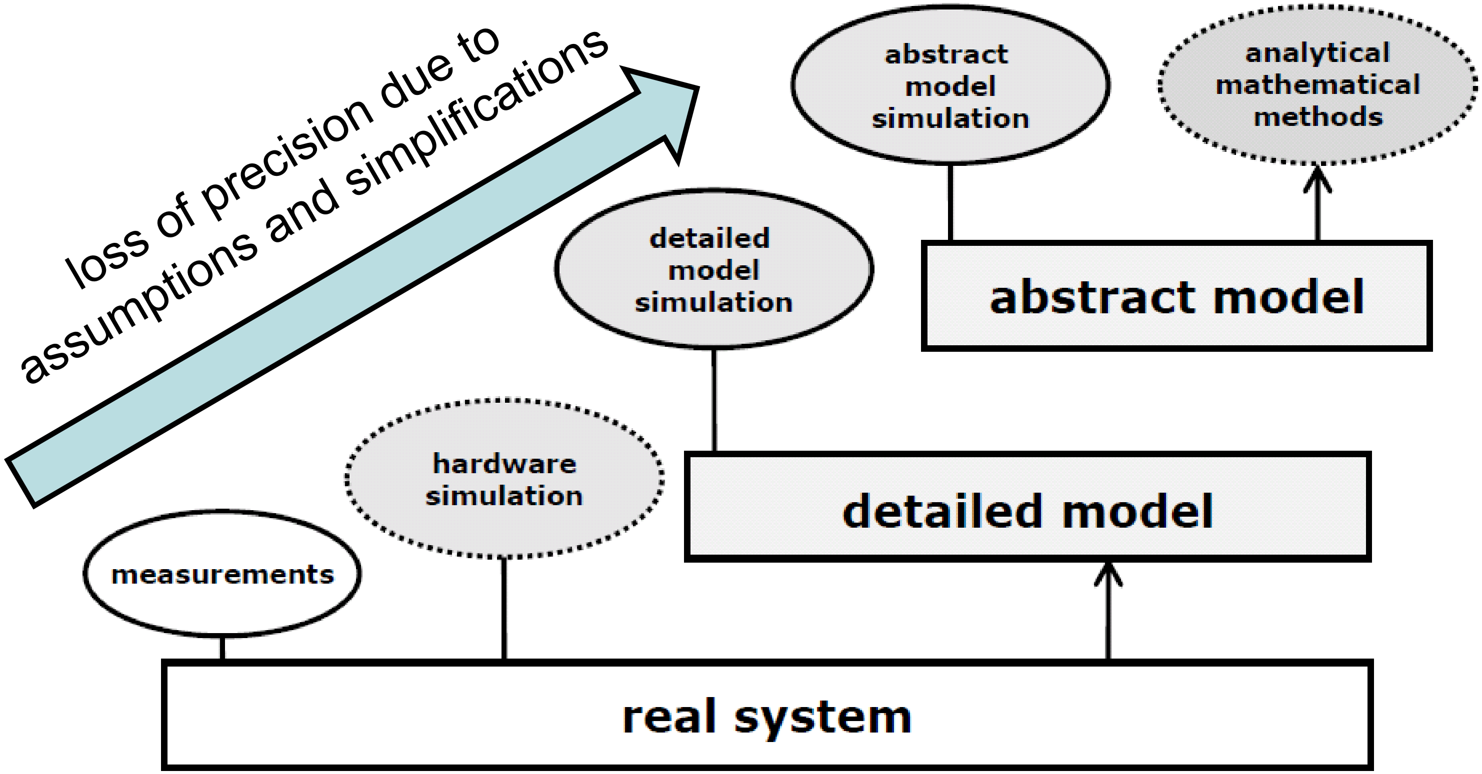
- In the following some slides on topics from the old course that we cover in either complete or (more often) reduced form.

Highlights from the Old Course

Simulation

- Simulation: What it is and when to use it
- Types of simulators
- Internals of discrete event simulators
- Continuations and co-routines

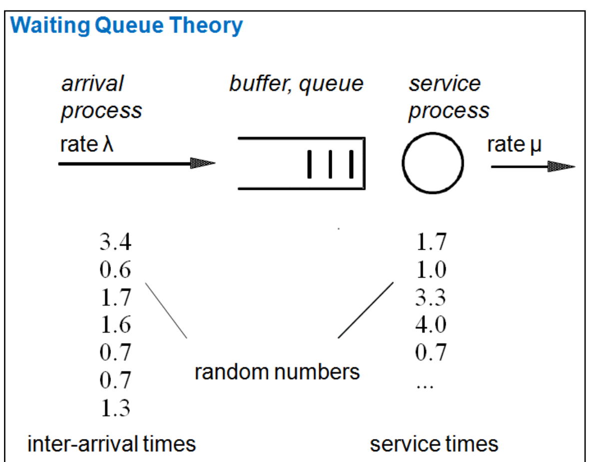


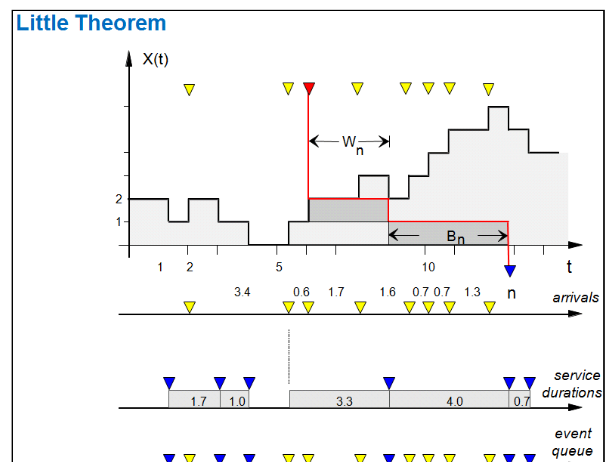


Highlights from the Old Course

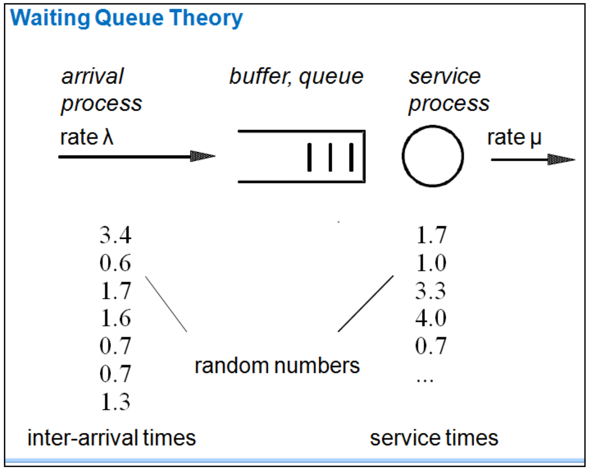
Statistics fundamentals

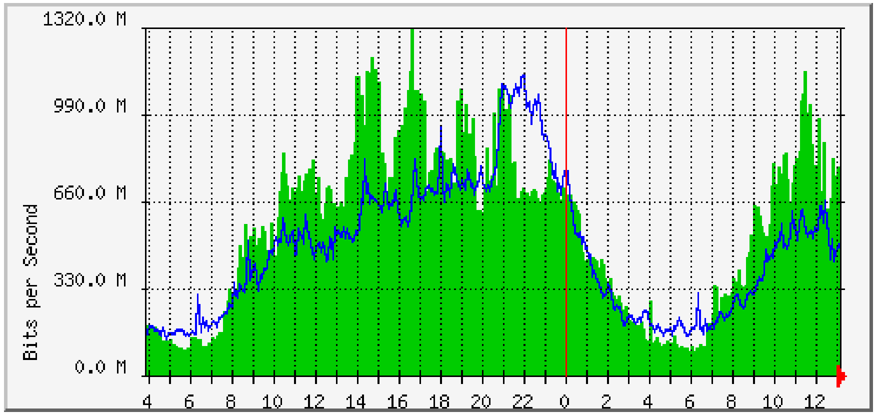
- Introduction to Waiting Queues
- Random Variable (RV), Discrete and Continuous RV
- Probability Space, Frequency Probability
- Distribution(discrete), Distribution Function(continuous)
- Probability Density Function, Cumulative Density Function
- Definitions: Expectation/Mean, Mode, Standard Deviation, Variance, Coefficient of Variation, p-percentile(quantile), Skewness, Scalability Issues, Covariance, Correlation, Autocorrelation Visualization of Correlation





Statistics fundamentals





Throughput MWN – Router - Garching

- Single high performance service process vs. multiple low performance service processes
- Impact for limited buffer size / storage capacity
- State / time dependent arrival process
- Performance parameters

Highlights from the Old Course

Random Numbers

- Random Variables:
  - Generation of Random Variables (RV)

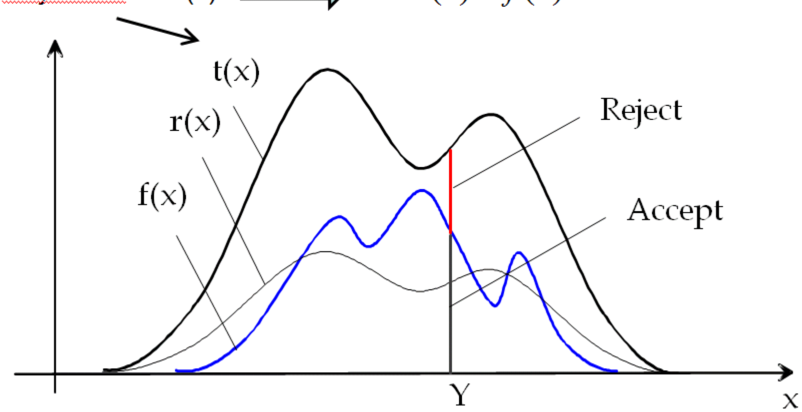
    Inversion, Composition, Convolution, Accept-Reject
  - Distributions and their Characteristics

    Uniform(continuous), Normal, Triangle, Lognormal, Exponential, Erlang-k, Gamma, Uniform(discrete), Bernoulli, Geom, Poisson, General Discrete

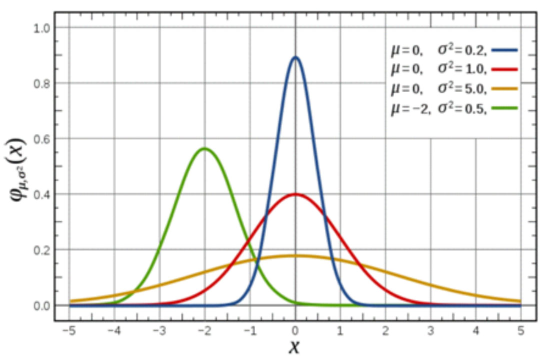
Accept-Reject

- Geometrical interpretation

  Y will be accepted if the point $(Y, U \cdot t(Y))$ falls under the curve *f*.
- The acceptance probability is high if *t(Y)-f(Y)* is small.
- Majorante von f(x) ⟹ $\forall x: t(x) \geq f(x)$



- **Normal distribution(3/3):**



Probability Density Function

Random Numbers

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Random 

Autocorrelation Lag 4

Highlights from the Old Course

Evaluation of simulation results:

- Consistent Estimator, Unbiased Estimator, Variance of an Estimator, Bessel's Correction, Efficient Calculation
- Confidence Interval
  - Chebyshev
  - Central Limit Theorem
  - t-Distribution
- Evaluation and comparison of Simulation Results Replicate-Delete Method, Batch Means Method, Stationarity

Confidence interval according to the central limit theorem

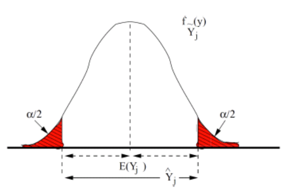
- Idea: The central limit theorem is still valid if σ^2 is replaced by $\tilde{S}^2$. Thus, it is possible to calculate the critical values out of the normal distribution.
- Recapitulate the “flipping of a coin example” with $\tilde{Y}$ representing the distribution of the estimator and Y being the distribution of the estimand. Then we can calculate the confidence interval as follows:

$$\Rightarrow \quad P[|Z| \geq \varepsilon] = P\left[\left|\frac{\tilde{Y} - E(Y)}{\tilde{S}/\sqrt{n}}\right| \geq \varepsilon\right] = \alpha$$

$$\Rightarrow \quad P[|\tilde{Y} - E(Y)| \geq \varepsilon \cdot \tilde{S}/\sqrt{n}] = \alpha$$

$$\Rightarrow \quad \boxed{\tilde{Y} \pm z_\alpha \cdot \tilde{S}/\sqrt{n}}$$

$\Rightarrow$ z_α is the $\alpha/2$ percentile of $N(0,1)$



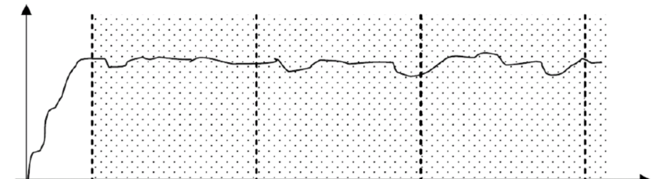
Picture taken from Buchholz

Batch-Means Method (LK 9.5.3)

- Estimate the duration of the transient phase
- Perform a long simulation run
- Remove the transient phase
- Divide the gathered results in n intervals of equal length (Batches) which hold m samples

$\Rightarrow$ Assure that the mean of subsequent batches is uncorrelated (calculate the empirical autocorrelation)

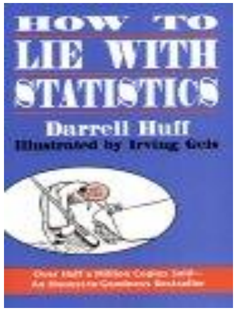
$\Rightarrow$ Number of batches $n \geq 10$ Batch size $m \geq 10 \cdot x$

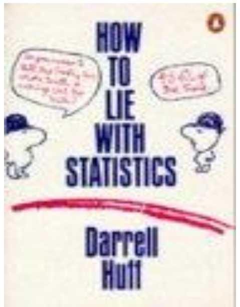


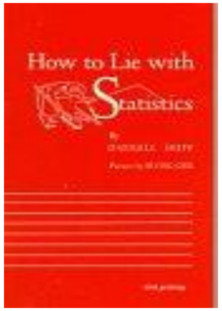
Highlights from the Old Course

How to Lie with Statistics:

- Lessons for Authors and Readers
- Examples and Discussion



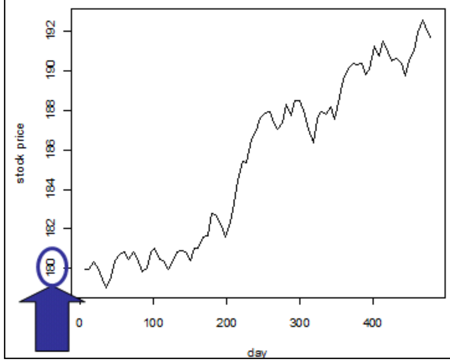


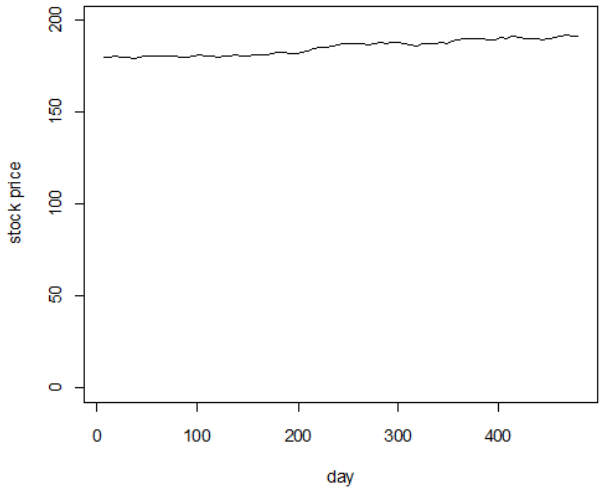


Scales can be misleading

- What really happened is shown here:

  We intuitively interpret a trend plot on a ratio





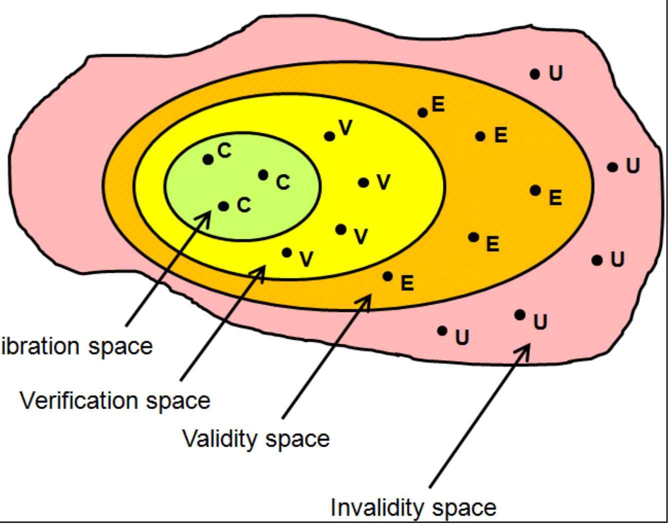
Highlights from the Old Course

Evaluation of simulation results:

- Model Validation:
  - Calibration, Overfitting
  - Structural Change, Parameter Change
  - Comparison of Confidence Intervals:

    Welsh, Law & Kelton

Calibration and Validation



Comparison of confidence intervals

Welch

- Estimators

$$\Rightarrow \quad \tilde{\mu}_R = \frac{1}{n}\cdot\sum_{i=1}^{n} V_{R_i} \qquad \tilde{S}_R^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(V_{R_i} - \tilde{\mu}_R\right)^2$$

$$\Rightarrow \quad \tilde{\mu}_S = \frac{1}{m}\cdot\sum_{i=1}^{m} V_{S_i} \qquad \tilde{S}_S^2 = \frac{1}{m-1}\sum_{i=1}^{m}\left(V_{S_i} - \tilde{\mu}_S\right)^2$$

- Difference of both samples are defined as follows:
  - $v_{RS\,i} = v_{Ri} - v_{Si}$
  - $v_{RS} = \{v_{RS_1}, v_{RS_2}, \ldots, v_{RS_n}\}$
  - $\tilde{\mu}_{RS} = \frac{1}{n}\cdot\sum_{i=1}^{n} V_{RS_i}$
  - $\tilde{S}_R^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(V_{R_i} - \tilde{\mu}_R\right)^2$

$$\Rightarrow \quad \boxed{\hat{\mu}_{RS} \pm t_{n-1,1-\alpha/2}\cdot \tilde{S}_{RS}/\sqrt{n}}$$

Both samples have to be statistically independent.

The samples must be of the same size. $m = n$

The variance of both samples must be equal. $Var(V_R) = Var(V_S)$

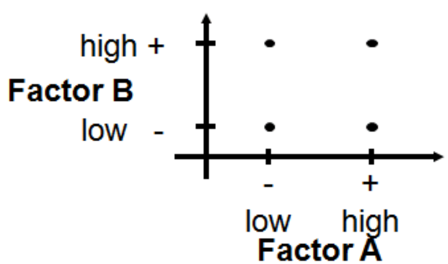
Highlights from the Old Course

Experiment planning:

- Hypothesis Testing
- Linear Regression
- Factorial Design

2^k factorial designs

- Example: 2 factors, i.e., a 2^2 design
- 4 design points:



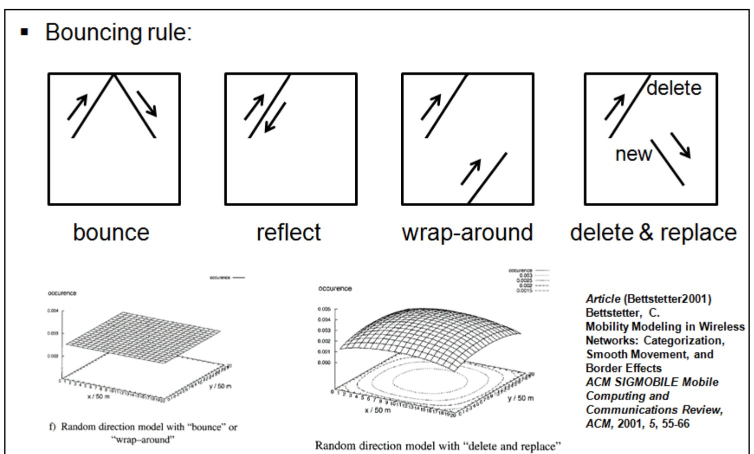
- Design matrix:

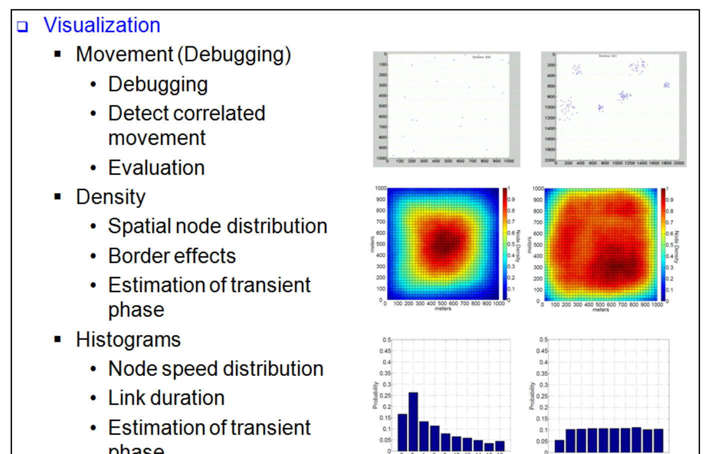
Run	Factor A	Factor B	Response
1	-	-	r_1
2	+	-	r_2
3	-	+	r_3
4	+	+	r_4

Highlights from the Old Course

Mobility:

- Mobility in General
  - Human Mobility Pattern
  - Visualization:
    - Density, Speed Histograms, Bouncing Rule, Obstacles
- Characteristics of Mobility Pattern:
  - Link Duration, Transient Phase, Node Distribution, Speed Distribution, Correlated Movement
- Synthetic Mobility Models:
  - Random Waypoint, Random Direction, Random Walk, Levi-Flight, Brownian Motion, Group Mobility

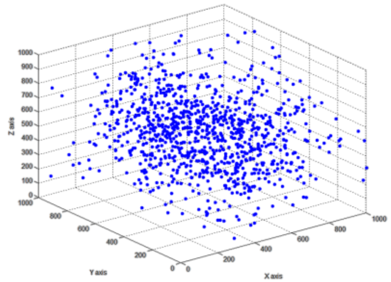


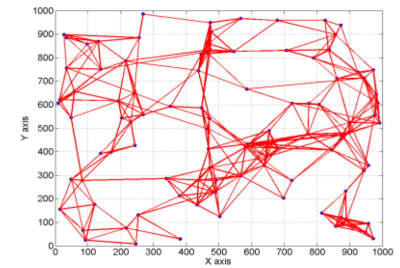


Highlights from the Old Course

Random Graphs:

- Graph Definition
- Generation of Random Graphs
- Probabilistic Model, Waxman Model
- Random Graphs with Predefined Characteristics
- Scale-free Graphs, Social-networks





- Scale-free networks – real-world examples:
  - **Social networks - Facebook:**

Facebook Friendships

Picture taken from http://www.opte.org

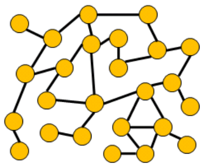
- **Scale-free graph:**

  A graph is called scale-free if its node degree k follows the power law.

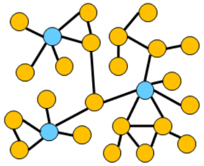
  $$P(k) = ck^{-\gamma}$$

  c and γ are constants. Typical range 0 < c < 1, 2 < γ < 3.

  - **Examples:**
    - Social networks
    - Collaboration networks
    - Computer networks
    - Disease transmission



Random Graph



Scale-free Graph